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## CONTENTS



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# THE INFLUENCE OF SEED-PIECE TREATMENT ON DISEASE CONTROL AND YIELD OF RUSSET BURBANK POTATOES[1]

JAMES W. GUTHRIE[2]

Research from past years (1,2,3,5,6,7,8,10) has shown that treating cut potato seed pieces with certain chemicals normally results in better germination, stronger plants and increased yields by protecting the seed pieces and young plants from degradation by soil-borne pathogens. In Idaho, however, the planting of untreated seed is becoming progressively more common. Reasons for this are numerous, but the ones most frequently encountered are: 1) failure of the grower to dilute the chemicals properly, resulting in poorer stands and lower yields than untreated sets, 2) unsatisfactory results with inadequately tested new chemicals, and 3) high cost of materials.

The most important of these is the improper dilution of chemicals. Many growers and warehouse operators attempt to maintain a constant volume in their treating tanks by adding more water or chemicals as needed instead of replacing the entire solution periodically with a fresh mixture. The addition of excessive amounts of chemicals, particularly those containing mercury, can cause severe burns on the seed pieces. The addition of too much water reduces the effectiveness of the treatment by diluting the chemical. In some instances, excess dilutions can actually create an inoculum bath of rot-producing organisms, particularly if ring rot bacteria are present.

The present study was made to compare some of the standard materials used for seed-piece treatment with new commercial fungicides and bactericides as seed-piece protectants. The chemicals used were further tested to determine their effectiveness when treated seed was held in storage for 10 days before planting and then planting in a dry versus an irrigated seed bed.

## METHODS AND MATERIALS

During 1956 and 1957, the following five chemicals were tested: Agrimycin (streptomycin 15.0 per cent and oxytetracycline 1.5 per cent), Phygon XL 2,3 dichloro-1, 4-napthoquinone 50 per cent), Semesan Bel (hydroxymercurinitrophenol 12.5 per cent and hydroxymercurichlorophenol 3.8 per cent), Captan 75 (N-(trichloromethylthio)-4-cyclohexene-1, 2-dicarboximide 75 per cent) and Terraclor 75 (pentachloronitrobenzene 75 per cent). The last four chemicals were also combined with Agrimycin; these, with an untreated check, made a total of ten treatments. Each chemical was mixed as follows: Agrimycin, 26 grams per 10 gallons; Phygon XL, 453 grams per 10 gallons; Semesan Bel, 648 grams per 10 gallons; Captan 75, 181 grams per 10 gallons and Terraclor 75, 453 grams per 10 gallons. The effect of each chemical on seed pieces held in storage after treatment was determined by dipping one sample of cut seed in each

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chemical ten days before planting and a second sample one day before planting. The seed pieces that were cut and treated 10 days before planting were placed in burlap bags and stored in the potato cellar until planting time. In an attempt to duplicate the actual storage conditions that are usually found in a commercial cellar, the bags were stacked with no special allowances made for optimum suberization.

Experiments were conducted in the University of Idaho Branch Experiment Stations at Parma and Aberdeen. The design used was a 10 x 10 Latin square split for dates of treatment. There was one major difference in procedure between the two locations. The seed bed at Aberdeen was irrigated before planting, whereas at Parma the seed bed was planted without pre-irrigation. Planting dates were April 17 at Parma, and May 14 at Aberdeen. All potato seed for both locations came from the same source. Two-row plots were planted for each treatment. At both locations the seed was planted with an assisted feed planter in rows 36 inches apart. The seed pieces were planted at a depth of 6 inches and spaces 12 inches apart in the row. The plants in one row were dug early to obtain disease indexes on both seed piece decay and Rhizoctonia damage to the stem. A disease index rating of 0 to 100 used for seed piece decay indicated that 0 was for no rot and 100 was for a completely rotted seed piece. A similar disease index was used for rating Rhizoctonia damage to the stem; 0 indicates that no lesions were present while 100 indicated that the underground plant structure was completely covered with lesions from the seed piece to the ground level or the plant destroyed due to Rhizoctonia. The second row of plants was left undisturbed for yield data. After they were harvested, the potatoes from each plot were sorted into grades of U.S. No. 1, No. 2 and culls, according to USDA standards. The grade U.S. No. 1 are those tubers with a 2 inch minimum diameter, more than 4 ounces, and of standard shape; U.S. No. 2 are off-grade tubers due to second growth and other blemishes rather than small size; Culls are small size or grossly malformed tubers.

## Results

When treated seed pieces were planted in irrigated soil, there were no statistically significant differences in yield among treatments, between any treatment and the check, or between dates of planting. This was true for total yield and also for yield of any of the three grades.

Statistically significant yield differences were recorded when the tubers were planted in dry soil that was not irrigated before planting (Table 1). When seed was planted one day after treatment, the total yield from seed treated with Semesan Bel( with or without Agrimycin), with Captan 75 (with or without Agrimycin), or with Phygon (with or without Agrimycin) was greater than that from untreated seed pieces. The same was true when yield was expressed in terms of U.S. No. 1 tubers. Only with the use of Captan 75 + Agrimycin and of Terraclor did treatment result in a greater yield of culls than was obtained from the controls. Agrimycin and Agrimycin plus Terraclor were detrimental since treatment with these materials resulted in a smaller yield than was obtained from untreated seed.

When seed pieces were stored 10 days between treatment and planting, only the use of Semesan Bel, with or without Agrimycin, resulted in

TABLE 1.—*Yield from cut seed potatoes treated with various chemicals and planted 1 or 10 days later in a field not irrigated before planting.*

| Time in Days from Treatment to Planting | Treatment | Yield (lb/plot)[1] of Tubers of Indicated Grade | | | |
|---|---|---|---|---|---|
| | | US No. 1 | US No. 2 | Culls | Total |
| 10 | Semesan Bel | 28.5 | 9.8 | 4.4 | 42.7 * |
| | Semesan Bel + Agri-mycin | 30.1** | 8.5 | 4.5 | 43.1** |
| | Captan 75 | 25.4 | 9.1 | 4.2 | 38.7 |
| | Captan 75 + Agri-mycin | 24.5 | 10.3 | 4.1 | 38.9 |
| | Terraclor | 28.3 | 7.6 | 3.9 | 39.8 |
| | Terraclor + Agri-mycin | 25.6 | 7.5 | 3.7* | 36.8 |
| | Phygon XL | 23.7 | 12.8** | 3.5** | 40.0 |
| | Phygon XL + Agri-mycin | 24.7 | 11.9** | 4.6 | 41.2 |
| | Agri-mycin | 25.0 | 9.0 | 3.9 | 38.0 |
| | None | 26.2 | 8.8 | 4.3 | 39.3 |
| | LSD (5 per cent) | 2.7 | 1.7 | 0.6 | 2.7 |
| | LSD (1 per cent) | 3.7 | 2.2 | 0.8 | 3.6 |
| 1 | Semesan Bel | 27.5* | 10.0 | 3.3 | 40.8* |
| | Semesan Bel + Agri-mycin | 27.1* | 9.5 | 4.0 | 40.7* |
| | Captan 75 | 27.5* | 10.8 | 3.6 | 41.9** |
| | Captan 75 + Agri-mycin | 28.8** | 10.1 | 4.1* | 43.0** |
| | Terraclor | 25.9 | 8.8 | 4.1* | 38.8 |
| | Terraclor + Agri-mycin | 22.6 | 7.3** | 3.6 | 33.4** |
| | Phygon XL | 27.0* | 10.8 | 3.7 | 41.5** |
| | Phygon XL + Agri-mycin | 26.9* | 10.3 | 3.9 | 41.1* |
| | Agri-mycin | 20.4** | 9.5 | 3.4 | 33.3** |
| | None | 24.1 | 10.3 | 3.5 | 37.9 |
| | LSD (5 per cent) | 2.7 | 1.7 | 0.6 | 2.7 |
| | LSD (1 per cent) | 3.7 | 2.2 | 0.8 | 3.6 |

[1]Plot size was 15 x 3 feet with 10 replications.
*A single asterisk indicates that the difference between the figure indicated and that for the check is statistically significant at the 5 per cent level.
**A double asterisk indicates significance at the 1 per cent level.

greater total yields than was given by the check. Only the use of Semesan Bel + Agrimycin resulted in significantly greater yields of U.S. No. 1 tubers than did the check.

*Rhizoctonia Control (Irrigated Soil)*

The seriousness of injury to the stems, roots, stolons, and immature tubers caused by *Rhizoctonia solani* Kuhn has probably been underestimated in relation to yield of marketable potatoes. In this experiment, potatoes grown from seed treated with Semesan Bel, Semesan Bel + Agrimycin, or Terraclor and held for 10 days before planting in irrigated soil had a lower Rhizoctonia index than did the control (Table 2). In irrigated soil, plants from seed pieces treated with Phygon XL + Agrimycin and held for 10 days had a higher Rhizoctonia index than did the control. The same was true for seed treated with Captan 75 and planted the day after treatment.

TABLE 2.—*Rhizoctonia and seed piece decay indexes following treatment of cut potato seed with various chemicals, storage of treated seed for 1 or 10 days, and planting in irrigated or dry soil.*

| Days between Treatment and Planting | Treatment | Condition of soil when planted | | | |
|---|---|---|---|---|---|
| | | Irrigated | | Dry | |
| | | Rhizoctonia Index[1] | Seed Piece Decay Index[2] | Rhizoctonia Index[1] | Seed Piece Decay Index[2] |
| 10 | Semesan Bel | 21** | 43** | 15** | 7** |
| | Semesan Bel + Agri-mycin | 20** | 40** | 22** | 6** |
| | Captan 75 | 38 | 44** | 27 | 8** |
| | Captan 75 + Agri-mycin | 34 | 46** | 25* | 14** |
| | Terraclor | 29* | 64 | 17** | 21** |
| | Terraclor + Agri-mycin . | 39 | 69 | 20* | 45 |
| | Phygon XL | 36 | 48** | 31 | 11** |
| | Phygon XL + Agri-mycin | 43* | 54* | 27 | 10** |
| | Agri-mycin | 35 | 71 | 27 | 45 |
| | None | 35 | 71 | 30 | 37 |
| | LSD (5 per cent) | 6 | 17 | 5 | 12 |
| | LSD (1 per cent) | 8 | 22 | 7 | 16 |
| 1 | Semesan Bel | 27 | 61** | 19** | 10** |
| | Semesan Bel + Agri-mycin | 25* | 52** | 15** | 2** |
| | Captan 75 | 43** | 57** | 24 | 8** |
| | Captan 75 + Agri-mycin | 36 | 62** | 23 | 15* |
| | Terraclor | 29 | 78 | 17** | 35 |
| | Terraclor + Agri-mycin | 35 | 78 | 23 | 43 |
| | Phygon XL | 37 | 47** | 27 | 11** |
| | Phygon XL + Agri-mycin | 37 | 43** | 22* | 10** |
| | Agri-mycin | 35 | 89 | 25 | 43 |
| | None | 32 | 87 | 27 | 29 |
| | LSD (5 per cent) | 6 | 17 | 5 | 12 |
| | LSD (1 per cent) | 8 | 22 | 7 | 16 |

[1]Rhizoctonia disease index rated from 0 to 100; 0 was for no lesions and 100 for underground plant parts completely covered with lesions.
[2]Seed piece disease index rated from 0 to 100; O was for no rot and 100 for completely rotted seed piece.
*A single asterisk indicates that the difference between the figure indicated and that for the check is statistically significant at the 5 per cent level.
**A double asterisk indicates significance at the 1 per cent level.

*Rhizoctonia Control (Dry Soil).*

Similar, although more pronounced, results were obtained when the seed pieces were planted in dry soil. In this case, use of Semesan Bel, Semesan Bel + Agrimycin, or Terraclor resulted in a lower Rhizoctonia index regardless of whether the seed was stored 1 day or 10 days before planting; the difference was statistically significant between treatments and check at the 1 per cent level. Seed treated with Captan 75 + Agrimycin or with Terraclor + Agrimycin resulted in a low Rhizoctonia index if held

for 10 days. A low disease index also resulted from the use of Phygon XL + Agrimycin one day prior to planting.

Every treatment used in this experiment, regardless of holding period or use of irrigation, except Agrimycin, Terraclor and Terraclor + Agrimycin resulted in a smaller amount of seed piece decay than resulted when untreated seed was used and Terraclor gave good control when seed was held 10 days and planted in dry soil. The difference was significant at the 1 per cent level. Semesan Bel + Agrimycin gave the most protection to the seed piece, particularly when the seed piece was planted in dry soil (Table 2). The predominate rotting organisms in Idaho are *Fusarium* species (4).

## Discussion and Summary

The results obtained from this experiment show that chemical treatment of cut potato seed will not only give good control of certain diseases but will also increase yields. This is particularly true under certain conditions. For example, failure of a seed piece treatment to increase yield when the treated seed pieces are planted in an irrigated seed bed as compared to a seed bed that had not been irrigated indicates that soil moisture is of great importance in the parasitic activity of certain pathogens. This was apparent in the case of *Rhizoctonia solani*. Peltier (5), Hofferbert (2), and Sanford (8) found that *R. solani* exhibited greatest parasitism when soil moisture content was either too low or too high for the best development of the host. In the experiments reported here, the least amount of Rhizoctonia injury was found when seed pieces had been treated with Semesan Bel, Semesan Bel + Agrimycin, or Terraclor and planted in dry soil. Treatments consisting of Captan 75 or Phygon XL with or without Agrimycin resulted in more infection in soils of high moisture content.

The amount of seed piece decay was partially controlled by all treatments except Agrimycin. The least decay was found where seed was treated with Semesan Bel, Captan 75, and Semesan Bel + Agrimycin. This is contrary to results obtained by other workers, (3,10), who state that seed treated with Semesan Bel must be planted immediately to prevent serious decay because of interference with suberization. Seed treated with Semesan Bel, if held for ten days, may develop a slimy coating over the cut surface. This is primarily due to various saprophytes that grow on the dead tissue caused by the action of the chemical. It has been the author's experience that seed treated with Semesan Bel and held even as long as a month was equal to or better than seed treated with any of the other standard commercial seed piece treatments held for the same time.

Materials containing Terraclor or Agrimycin alone or in combination with each other were quite outstanding in their inability to prevent seed piece decay. In the case of Terraclor, this was unexpected, since the active ingredient, pentachloronitrobenzene, is primarily a fungicide; it apparently is not effective against the common seed-rotting organisms. Agrimycin, on the other hand, is composed of streptomycin and oxytetracycline, both of which are generally considered to be specific bacteriostatic agents. According to Waggoner (9), streptomycin increased the susceptibility of potato slices to Fusarium decay. Nielson (4) found that *Fusarium* species were

the predominate rotting organisms of the seed pieces in Idaho soil. This may account for the lack of protection afforded by Agrimycin.

No large differences in yield of U. S. No. 1 potatoes were found when cut seed was treated with either Semesan Bel, Captan 75, or Phygon, with or without the addition of Agrimycin, if planted the day following treatment. Of all the treatments used, only use of Semesan Bel plus Agrimycin resulted in an appreciably greater yield than was obtained from untreated seed if the seed pieces were held for ten days. Since Semesan Bel and Agrimycin have been reported to be effective in the control of black leg, (1, 10), seed piece decay (10), Rhizoctonia (10), and Verticilium wilt (6, 7, 10) and since their use may result in better yields than is obtained following use of untreated seed, it is recommended that the combination of these two chemicals be used for treating potato sets in Idaho.

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# THE PEROXIDASE TEST AS A TOOL IN THE SELECTION OF POTATO VARIETIES RESISTANT TO LATE BLIGHT[1]

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Our present knowledge on the mechanism of resistance to the late blight pathogen (*Phytophthora infestans* (Mont.) De By.) in the potato (*Solanum tuberosum* L.) is based mainly on contributions of Müller and coworkers (11, 12, 13, 14). After attack by the fungus, resistant plants show necrotic reactions relatively fast, whereas susceptible plants exhibit a similar but delayed reaction. The dark-colored products appearing after necrosis of the host tissue seem to be oxidized phenolic substances (11). Although these substances have not been clearly identified, Müller (12) has proved that "protecting substances," produced by the host cells of certain plants after invasion by the fungus, are the final result of the necrotic reaction. At certain concentrations, the protecting substances, termed "phytoalexines," have fungistatic or fungicidal properties. In susceptible varieties, necrosis and production of "phytoalexines" are delayed. Therefore, the fungus is able to invade new host cells and to develop spores on the surface of invaded tissues.

Treatment of potato tubers with substances which inhibit or decrease enzyme activity of the tissue changes the resistance behavior of the tubers (1): resistant ones become susceptible, and the degree of resistance of previously susceptible tubers becomes still lower. Inhibition of polyphenol oxidase permits growth of hyphae and production of spores on the surface of previously resistant tubers (4). Substances nonspecifically inhibiting the activity of Cu- and Fe-containing enzymes decrease resistance of treated tubers even more strongly than do specific polyphenol oxidase inhibitors. Therefore, the Fe-containing peroxidase has been considered as a possible additional factor determining resistance.

A different experimental approach to the same problem has been made by other investigators (6, 9), who found correlations between the level of activity of peroxidase in potato tissue before infection by the fungus and the degree of resistance of the variety tested. Grechushnikov (6) measured (*in vitro*) the peroxidase activity of leaves and tubers of a few varieties and concluded that resistant varieties usually show higher enzyme activity than do more susceptible ones. Similar conclusions were arrived at by Kammermann (9) who measured the peroxidase activity of crude sap of leaves from a large number of potato varieties. It may be argued, then, that a potato variety with high peroxidase activity has the potentiality for a relatively fast necrotic reaction — shown after the plants are attacked by the pathogen.

From the genetical point of view, resistance of the potato to the late blight fungus is based on two different groups of factors. Major genes such as $R_1$, $R_2$, and $R_3$, all derived originally from *Solanum demissum* (Lindl.) provide protection against certain races of the fungus

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(2). The so called "minor genes," found in varieties of *S. tuberosum*, apparently provide a certain degree of resistance against all races of the pathogen, but even the most resistant varieties of this type usually show damage when ecological conditions are favorable for development and spread of the fungus. Minor gene resistance, also called field resistance, hereafter is designated by the letters *rr*. This designation does not imply any allellic relationship between *rr* and *R* genes.

The experiments to be reported here were initiated in order to determine whether any correlation exists between the activity of peroxidase in crude sap of healthy potato foliage and the two types of resistance mentioned above. Additionally, a survey of some of the theoretical and practical implications of the peroxidase test will be attempted.

## Materials and Methods

Potato plants for the determination of enzyme activity were grown in the field and in pots in the greenhouse. The resistance of the varieties to late blight was graded from 3 to 9 according to data collected by Hogen Esch (8). Degree 3 indicates very susceptible, degree 9 resistant, and degrees 4 to 8 intermediate degrees of resistance. In certain cases, mentioned later, plants were classified according to observations in the field or according to their reaction after artificial inoculation in moist chambers.

Leaves were taken at mid-height from ten plants of each variety, when plants were 9-10 weeks of age. After the surfaces of the leaves were washed and dried, two random samples of 4 grams each were prepared. One sample was used for dry-weight determinations, whereas the second was ground thoroughly in a mortar. The crude sap obtained was then filtered through 3 layers of gauze, and the remaining tissues were extracted with 80 ml. distilled water. This sap preparation (crude sap diluted with 80 ml. distilled water) is henceforth called S.P. One ml S.P. then was added to 20 ml distilled water and 20 ml McIlvain's (7) Phosphate-citrate buffer of pH 6. The sample thus obtained (called P.S.P.) was used for determination of enzyme activity. Centrifugation of the P.S.P. proved unnecessary.

An estimation of peroxidase activity (henceforth called P.A.) was made with a Lange Photoelectric Colorimeter. A blue filter (no. 622) was used, and the instrument was adjusted to zero after the insertion of a colorimetric tube containing distilled water. Guaiacol, which in the presence of the enzyme and hydrogen peroxide is oxidized to the brown-red tetraguaiacol, was used as an indicator. Of a solution of 1 per cent guaiacol in absolute ethanol, 1 ml was pipetted into 50-cc Erlenmeyer flasks. One ml of 0.5 per cent hydrogen peroxide was added, and finally 5 ml of the P.S.P. was pipetted into each flask; the reaction was timed with a stopwatch started simultaneously with the addition of the P.S.P. The flasks were shaken for 15 seconds, after which the contents were poured into 7.5-cc colorimetric tubes. Colorimetric readings were taken from one-half to four minutes, at intervals of 30 seconds. Enzyme activity was measured as the increase in extinction values (E x 100) between 2 and 4 minutes. Each P.S.P. sample was tested twice, and the mean was taken as an estimation of the P.A. of the sample. All figures obtained

were transferred to the basis of 1 gram dry matter and compared with P.A. of the standard variety, Up-to-Date, on a percentage basis.

Enzyme activity of the standard variety, measured as outlined above, increased proportionally when 0.5, 1.0, and 2.0 ml of S.P. were used in preparing the P.S.P. solutions.

A simplified routine test for use in the selection of plants with very high or very low enzyme activity can be developed by a combination of technics described by different authors (3, 9, 10). Fairly satisfactory results can be obtained with the following methods. A few leaves enclosed in gauze tissue are pressed between jaws of a tong, and drops of crude sap from different varieties are collected on separate pieces of filter paper. After the paper has dried a few minutes, it is put into a solution of hydrogen peroxide (0.5 per cent) and then transferred into guaiacol (10 per cent in absolute alcohol) for a few seconds. After 6 to 8 minutes, darkness of the brown-red color developed indicates the P.A. of the crude sap. A 1:1 mixture of 1 per cent hydrogen peroxide and 4 per cent guaiacol can be used instead of two separate containers for the two solutions.

## Results

### *The Correlation between Resistance and Activity of Peroxidase.*

Leaves were collected from field-grown plants of sixteen varieties, whose degrees of resistance to "common" races (as *0* or *4*) varied between 3 (very susceptible) and 9 (resistant).

No generally valid correlation was found between resistance and relative activity of peroxidase (Table 1). Resistant varieties, all graded "9" in table 1, show percentages of peroxidase activity between 40 and 190. All these varieties belong to "resistance - genotype" $R_1$ (2). Remaining varieties are of resistance type *rr* (minor gene or field resitsance), with degrees of resistance varying between 3 and 8. Dividing the material according to resistance genotype and considering *rr* varieties only, we find a correlation coefficient of $r = 0.938$, a regression coefficient of $b = 0.036$ and $P<0.01$. It is obvious then that a highly significant correlation exists between the level of peroxidase activity of the crude sap of potato leaves and the degree of resistance of varieties belonging to the *rr* resistance genotype. No such correlation exists between high resistance based on $R_1$ genes and activity of the enzyme; varieties of this group ($R_1$), may show high, medium or low peroxidase activity.

### *Minor Gene Resistance and Peroxidase Activity.*

The potentials and limitations of the peroxidase test in regard to material with different degrees of "field resistance" based on minor genes (*rr*) are illustrated in table 2. Methods used are similar to those in the above experiment, but degrees of resistance are based on field observations under Israeli conditions. They differ slightly from values given by Hogen-Esch (8).

Again a significant correlation was found between resistance and peroxidase activity (Table 2); however, the variety Ostbote, classified as highly resistant, did show medium enzyme activity only. The reason for this discrepancy is not entirely clear. Other authors (15, 16) have

TABLE 1.—*Resistance to common races of late blight (0 or 4) and activity of peroxidase in 16 potato varieties.*

| Variety | Resistance Rating[1] | Resistance Genotype[2] | Relative Peroxidase Activity[3] |
|---|---|---|---|
| Jakobi | 9 | $R_1$ | 190 |
| Maritta | 9 | $R_1$ | 110 |
| Kennebec[4] | 9 | $R_1$ | 100 |
| Frühnudel | 9 | $R_1$ | 95 |
| Falke | 9 | $R_1$ | 81 |
| Empire[4] | 9 | $R_1$ | 70 |
| Roswitha[4] | 9 | $R_1$ | 40 |
| Dar[4] | 8 | rr | 185 |
| President | 7 | rr | 170 |
| Ontario | 7 | rr | 180 |
| President | 7 | rr | 160 |
| Alpha | 7 | rr | 140 |
| Ari | 6 | rr | 110 |
| Sientje | 5 | rr | 120 |
| Sebago | 5 | rr | 110 |
| Up-to-Date (Standard) | 5 | rr | 100 |
| Bintje | 3 | rr | 80 |
| Bintje | 3 | rr | 45 |

Correlation coefficient $r = .175$, $b = .008$, $.05 < P$. (all varieties); rr—varieties only: $r = .938$, $b, = .036$, $P < .01$.

[1] 3 = very susceptible, 9 = resistant.
[2] rr = Minor gene resistance, $R_1$ = Major gene resistance.
[3] Percentage of the control, when results were calculated as relative activity per gm. of dry weight.
[4] Resistance graded according to trials in Israel.

TABLE 2.—*Resistance to common races of late blight (0 or 4) and peroxidase activity of potato varieties belonging to the rr - resistance group.*

| Variety | Resistance[1] | Relative Peroxidase Activity[2] |
|---|---|---|
| Ultimus | 8 | 325 |
| Noord - Star | 8 | 263 |
| Dar | 8 | 225 |
| Knick | 8 | 225 |
| Ostbote | 8 | 156 |
| Up-to-Date | 4 | 100 |
| Houma | 3 | 131 |
| Marygold | 3 | 163 |
| Irish Cobbler | 3 | 100 |

$r = .768$ $b = .025$ $.01 < P < .05$

[1] 3 = very susceptible, 8 = highly resistant. Based on field observations under Israel conditions.
[2] As percentage of the peroxidase activity of the control ,(Up-to-Date).

classified the same variety as medium or highly susceptible — which is more in accordance with the peroxidase value found here.

Table 2 even shows that one could select the four highly resistant varieties by a single nonreplicated P.A. test. Although P.A. values of susceptible and very susceptible varieties differ rather widely, they do not approximate those of the highly resistant group.

*Peroxidase Activity and the Relative Resistance of $R_1$-Varieties after Attack by Compatible Races.*

Gene $R_1$ provides resistance to a number of pathogenic races of *P. infestans*; however, $R_1$-varieties are susceptible to race 1, to race 1,4, and to some other races of the fungus (2). An experiment was designed to determine whether the degree of resistance or susceptibility shown by $R_1$ varieties to race 1,4 could be characterized by the P.A. of healthy leaves of the same varieties. As only sparse literature on the relative susceptibility of $R_1$ varieties to compatible races is available, all plants were inoculated artificially and the severity of disease symptoms was valuated.

A plant section (stem with leaves) reaching from the top of the plant to 40 cm below was cut from field-grown plants two and a half months old. After a washing in tap water, the base of the stems with leaves still attached was put into water in glass jars. After the surface of the leaves had dried, three leaflets on each plant were inoculated with a suspension of zoospores of race 1,4. Four drops of the suspension were applied on each leaflet. Plants were then covered by bell jars with moist filter paper inside. The temperature ranged from 18°-20° C. during the day, and 15°-16° C. at night. Samples were taken for enzyme determination before inoculation.

Resistance of $R_1$ varieties to race 1,4 was correlated with peroxidase activity (Table 3). On the basis of the P.A. test, Dar (probably synonymous with Ackersegen) would be characterized as highly resistant and four varieties, including Panther and Cr. Snow White, as very susceptible. The remaining varieties were intermediate. These ratings agree well with ratings based on inoculation experiments with race 1,4.

Further evidence in connection with the correlation between P.A. and resistance is provided by a comparison of P.A. figures from table 3 and data on fructification intensity given by other authors (15). These investigators graded resistance of $R_1$ varieties in a detached-leaf test after artificial inoculation with a compatible race ($B$) of the fungus. An exerpt from their results (15, Table 9), supplemented by P.A. figures from our tabel 3, are given in table 4. These data indicate that $R_1$ varieties characterized by very low P.A. will permit heavy producton of sporangia when infected by a compatible race.

## Discussions and Conclusions

*Theoretical Considerations.* Field resistance of the potato to late blight is a complex phenomenon involving widely different factors, such as vigor of plant growth and the resulting microclimate in the field, varietal differences in resistance of leaves to infection, speed of mycelial growth in the leaf tissues, and intensity and time of fructification. Therefore, any attempt to explain field resistance on the basis of a single factor such as

TABLE 3.—*Disease symptoms of leaves of $R_1$ varietes of potato 96 hours after inoculation with race 1,4 of Phytophthora infestans and peroxidase activity of healthy leaves.*

| Variety | Speed of Fungus Growth[1] Mm. | Diameter of Necrotic Spots[2] Mm. | Relative Degree of Resistance[3] | Relative Peroxidase Activity[4] |
|---|---|---|---|---|
| Dar[5] | 10 | 5 | 8 | 152 |
| Maritta | 10 | 6 | 7 | 129 |
| Plymouth | 7 | 4 | 7 | 129 |
| B 355-44 | 14 | 8 | 6 | 129 |
| Boone | 25 | 10 | 5 | 114 |
| B 69-16 | 15 | 8 | 5 | 105 |
| Up-to-Date[5] | 20 | 10 | 4 | 100 |
| Cr. Snow White | 12 | 12 | 5 | 76 |
| Roswitha | 30 | 10 | 4 | 71 |
| Panther | 20 | 10 | 5 | 62 |
| | | $r = .807$ | $b = .037$ | $P < .01$ |

[1]Mean diameter of visibly infected area around primary infection spots.
[2]Mean diameter of the brown necrotic part of the area infected.
[3]8 = highly resistant, 7-5 = intermediate degrees, 4 = very susceptible.
Figures are given according to general impression on severity of fungus attack.
[4]As percentage of standard (Up-to-Date).
[5]*rr*—Variety.

TABLE 4.—*Peroxidase activity of extracts of 4 potato varieties (with $R_1$ or rr resistance) and intensity of fructification of a compatible race (B) of P. infestans on detached leaves.*

| Variety | Resistance Genotype | Relative Amount of Fructification[1] | | Relative Peroxidase Activity[2] |
|---|---|---|---|---|
| | | Third Day | Fourth Day | |
| Ackersegen[3] | *rr* | 1 | 2 | (152)[3] |
| Maritta | $R_1$ | 2 | 4 | 129 |
| Roswitha | $R_1$ | 3 | 4 | 71 |
| Panther | $R_1$ | 5 | 5 | 62 |

[1]Data from Rudolf and Schaper (15); 1 = low intensity, 5 = high intensity.
[2]From Table 3.
[3]P.A. value for variety Dar, which is presumed to be synonymous with Ackersegen.

peroxidase activity is not warranted. But the question arises as to whether activity of peroxidase can be considered as one of the factors involved. Two different experimental approaches to this question have been reported. In the work presented here, as in other experimental results (6,9), a correlation between a high peroxidase activity and a high degree of resistance has been found in *rr* varieties. A similar relationship becomes evident in $R_1$ varieties, once the "masking" effect of the $R_1$ gene has been overcome by a compatible strain of the fungus. These results suggest that high activity of the enzyme may be one of the factors responsible for high resistance.

It may be argued, however, that genes for high peroxidase activity

may be genetically linked with the true resistance factors. Some observations oppose this supposition. Among a considerable number of potato varieties tested, no combination of high resistance and very low P.A. or low resistance and very high P.A. has been found.

A different approach to the same problem has been made by Christiansen-Weniger 4), who applied various enzyme inhibitors to potato tubers and found that compounds inhibiting both Fe- and Cu-containing enzymes are more effective in reducing tuber resistance than are compounds inhibiting Cu-containing enzymes only. The Cu-containing enzyme inhibited by the above treatment was thought to be polyphenol oxidase, and the Fe-containing enzyme involved has been considered to be peroxidase. It must be kept in mind, however, that a decrease in resistance resulting from inhibition of a certain enzyme does not necessarily imply that the activity level of this enzyme acts as a decisive or limiting factor in resistance of normal nontreated plant material. It may be that the level of enzyme activity normally present in a very susceptible variety is entirely sufficient to permit the expression of other resistance factors.

The experimental evidence available hitherto does not give sufficient proof for a causal relationship between P.A. and resistance; however, no facts contradicting such an assumption have been found. It could be argued that varieties which possess a high potentiality for P.A. before infection by the fungus may be able to produce phytoalexines relatively fast after invasion by the fungus and thus exhibit a relatively high degree of resistance.

The hypothesis usually forwarded is that necrosis (and production of "phytoalexines") is caused by excessive oxidation of phenolic substances. The activity level of the peroxidases may then be one of the limiting factors in this process. Extensive discussions of this subject may be found in the literature (12, 4, 5).

It is interesting to note that resistance based on *R* genes is usually considered as the highest degree of a continually increasing scale ranging from very susceptible to resistant. Certain similarities between susceptible and resistant varieties have been found in cytological studies of the host-pathogen relationship. Consequently, resistance based on *rr* genes and resistance based on *R* genes are frequently treated as similar phenomena both in experimental and in theoretical approaches. But differences in genetical background, in the relationship between resistance and P.A., and in other characters seem to make imperative a clear distinction between the two types of resistance.

*Practical Considerations.* Breeding of *Phytophthora*-resistant potato varieties is a major objective in many potato-growing countries. With the appearance of highly aggressive pathogenic races of the fungus, major gene resistance has proved insufficient, and renewed emphasis has been placed on field resistance based on minor genes. Yet minor gene varieties possessing very high resistance to the pathogen have never been reported. Such a high degree of resitsance is exhibited only by major gene varieties in relation to incompatible races of the fungus. It has been found, however, that plants of the potato accession *Morada silvestre,*[3] said to be

[3]Kindly provided by Dr. J. S. Niederhauser, Rockefeller Foundation, Mexico D.F., Mexico.

highly resistant to all races of the pathogen, are characterized by exceptionally high P.A.[4] It is unknown, at present, whether commercial varieties with such a high degree of resistance to all races could be produced by the incorporation of factors responsible for very high peroxidase activity.

The method almost exclusively used for evaluating degrees of resistance of breeding material has in the past been biological, *i.e.*, natural or artificial inoculation of the material followed by evaluation of disease symptoms. These methods have proved rather effective for *rr* varieties. A peroxidase test for evaluating "field resistance," based on the correlation between resistance and enzyme activity, will probably be less satisfactory than the biological methods commonly used. The P.A. test will permit the selection of highly resistant plants or the elimination of very susceptible ones, but the evaluation of plants with less extreme degrees of resistance will hardly be reliable.

No correlation between $R_1$ genes and peroxidase activity exists, and the P.A. test at first might appear useless for the evaluation of breeding material containing major ($R$) genes as factors for resistance. But we may recollect that the protective effect of the $R$ genes is overcome when an $R$ variety is attacked by a compatible race. The relative resistance of such a variety then depends mainly or entirely on other resistance factors, *i.e.*, on the minor genes (*rr*) present in the $R$ variety. Many potato varieties containing $R$ genes seem to possess very few of the *rr*-resistance factors. Once they are attacked by a virulent strain of a compatible race, they become more susceptible than some *rr*-varieties which exhibit relatively high field resistance against all races of the pathogen. It is obvious that an $R$ variety possessing strong *rr* resistance factors will remain highly field resistant even after attack by a compatible race; additionally, the chances of such a variety becoming infected by a compatible race of the fungus would probably be much reduced at least in areas where such races are not previously found so they would have to arise, probably by mutations, from common strains.

What are the methods then, which can be used in producing varieties containing a maximum of different $R$ genes, reinforced by resistance factors of the *rr* type?

$R_1$ varieties have been shown to differ widely in their peroxidase activity. Varieties of this type even exhibit different degrees of resistance when attacked by race *1,4* of the fungus (Table 3). This degree of resistance, dependent apparently on the effect of the minor genes present, seems to a certain extent to be predictable by the P.A. test, as was the case with varieties lacking $R$ genes. An $R_1$ variety characterized by very high peroxidase activity will in most or all cases remain highly resistant even after attack by race *1,4*, whereas an $R_1$ variety with very low P.A. will become very susceptible.

Some of the situations which may arise in breeding for resistance will now be discussed more extensively. If, for example, $R_1$ seedlings have been produced, those with strong *rr* factors can be selected by 1] the P.A. test or 2] the biological test with a compatible race of the parasite.

In the selection of seedlings with two different $R$ genes (*e.g.* $R_1$, $R_2$) reinforced by minor genes, a similar procedure may be followed. Seedlings

[4]Unpublished data of the author.

resistant to race *1* and race*2* must be selected first. Selection for minor gene resistance can then be made by the P.A. test or by artificial inoculation with race *1,2*. This additional biological test involves some difficulties. If plants in the seedling stage are inoculated, even some of the more resistant ones may die. If the detached-leaf technic is used, tests for *rr* resistance will give tentative results only. Additionally, the virulence of race *1,2* will have to be maintained and checked in all trials. Here, the P.A. test seems to have several advantages over the biological test.

If a still larger number of different *R* genes ($R_1$, $R_2$, $R_3$, $R_4$) should be incorporated into a variety with maximum *rr* factors, the additional test for *rr* factors will involve infection of the material by race *1,2,3,4*. In many instances, it may seem preferable to apply the P.A. test instead of the biological one. In areas where this aggressive race has not been found, the breeder may not be interested in importing it to his country. He would be forced to increase his seedlings a second year and to send the clones to other countries for evaluation. Here, the peroxidase test seems definitely the more promising one, as selection can be made in the seedling stage without danger of loss of promising seedlings by infection and without the need to await results of evaluation made in other countries.

Finally, if we are dealing with seedlings resistant to all known races of *P. infestans,* the only possiblity for checking strength of *rr* resistance factors seems, at present at least, to be the chemical P.A. test.

The results presented in the present paper give only part of the experimental evidence needed; there are still a number of aspects which need further attention. Experimental procedure should be standardized as much as possible, and a standard variety or homozygous seedlings of high P.A. should be included in all tests in order to allow comparisons. Finally, the assumption that the correlation between P.A. and resistance is true even for *R* material other than $R_1$, and for seedlings as well as for clones, should be tested experimentally.

## Summary

When the crude saps of leaves of healthy potato plants were tested for relative peroxidase activity, a positive correlation was found between peroxidase activity and the degree of resistance to *Phytophthora infestans.* This correlation was true for varieties whose resistance is based on minor genes (*rr*). A similar correlation was found between peroxidase activity and the degree of resistance exhibited by $R_1$ varieties to the compatible race *1,4* of the fungus. It is indicated that a peroxidase test may be useful as an additional tool in the selection of $R_1$ varieties which are reinforced by minor genes responsible for a high degree of field resistance. The peroxidase test may prove reliable even for breeding material with *R* genes other than $R_1$.

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# POTATO PRODUCTION IN DRYLAND ROTATIONS IN WESTERN NEBRASKA THROUGHOUT A TWENTY-THREE YEAR PERIOD[1]

R. B. O'KEEFE AND H. O. WERNER[2]

## INTRODUCTION

In 1930, when the series of rotations were started at the Box Butte Experiment Farm (near Alliance, Nebraska), little information was available concerning the effect of different crop rotations on yield and quality of potatoes under dryland conditions on the High Plains. One of the major objectives was to ascertain the best dryland rotation practices for the production of potatoes. The experimental results for all crops (potato and grain) included in the study for the period 1931-1940 have been reported together with a summary of prevailing weather conditions (1). The results which specifically pertain to potato production for the 1931-1953 period, with special attention to the 1941-1953 period, along with a summary of the weather conditions are presented herein.

## WEATHER CONDITIONS

The annual total precipitation (October 1 to September 30) during the twenty-three years varied from 9.08 inches in 1934 to 23.01 inches in 1942 and effective precipitation (0.5 inches in 48 hours) varied from 4.07 inches in 1940 to 16.87 inches in 1942. In each of seven years of the 1941-1953 period the total precipitation was greater than the 53 year average (16.33 inches), and the effective precipitation was above the long time mean (11.32 inches). In contrast, during the first decade (1931-1940) the annual total and effective precipitation means exceeded the 53 year means in only three of the years.

The mean temperature during the 1941-1953 period for the potato growing season (July 1 to September 30) was 67.7° F. The 23 year mean temperature for this period was 68.6° F.

The air movement averaged 7.55 miles per hour for the months of May through September for the 13 year period, 1941-1953. This was 0.23 miles per hour faster than for the same months during the 1931-1940 decade. In 1941-1953 the mean rate of air movement was greater than in the 10 previous years in each of the months except June. The average velocity of wind for the 23 year period was 6.92 miles per hour.

The direct contrast in general climatic conditions during the two major periods is apparent from the rate of evaporation records. Total mean evaporation from June 1 to September 30 was 30.16 inches for the 1941-1953 period which was 7.00 inches less than for the same period during the 1931-1940 decade.

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The average length of the frost free growing season for the 23 year period was 132 days. The shortest was 87 days (1942) and the longest was 162 days (1938).

Hailstorms caused slight to moderate damage to potato vines in 1943, 1944, 1945, 1946 and 1948, and severe damage in 1932 and 1950.

## Materials and Methods[3]

Three fields of approximately 6 acres each were devoted to the rotation study. Replication was provided by having one complete set of rotations in each of three fields within each of which soil conditions were relatively uniform. The soil was of the Rosebud series with a soil moisture field carrying capacity varying from 12.5 to 18.5 per cent for various 1 foot levels to a depth of 5 feet. Calculated as inches, the capacity of the soil for available moisture varied from 1.1 to 1.7 inches per foot of depth. The amount of available moisture present in the soil at the time of potato plant emergence and immediately prior to harvest was determined for each series of rotations in most years by sampling to a depth of 5 feet by 1 foot intervals.

The Triumph variety was used in all rotations from 1931 through 1950 but was replaced by Progress in 1951. Seed bed preparation consisted of plowing and harrowing in early June. Potatoes were planted between June 15 and 22 with either a single or two row planter. Rows were 40 inches apart with seed pieces spaced 14.5 inches. The size of the plots was one-tenth acre.

In most years potatoes were harvested the first week of October. The potatoes from each plot were stored in separate containers for several weeks after which they were sorted for grade and defects. The grade factors considered were total and U. S. No. 1 yields, size, type, roughness, harvest cracks, cuts and scab.

## Experimental Results

*Effects of Precipitation.* — The predominant factor influencing potato yield was the annual amount of effective precipitation (October 1 to September 30) (Figure 1). Both the annual effective precipitation and its distribution had a great effect upon total yield. The high potato yields were produced in seasons when effective pre-planting precipitation (October 1 to June 1) of 5.75 inches or more was followed by more than 2.5 inches of effective summer rain. The crop years[4] 1945, 1949, and 1951 were notable exceptions. In these years, the effective pre-planting precipitation was less than three inches, but was followed by abundant precipitation from June through September. Yields for these years were high and the highest average yields for the 23 year period were produced in 1945 and 1951. With ample preplanting soil moisture, rainfall occurring in August and September was generally of greatest value for increasing yields; early August rains were the most effective (1).

[3]For greater detail concerning methods see reference (1).

[4]Crop year when considering soil moisture aspects is considered as being October 1 to September 30.

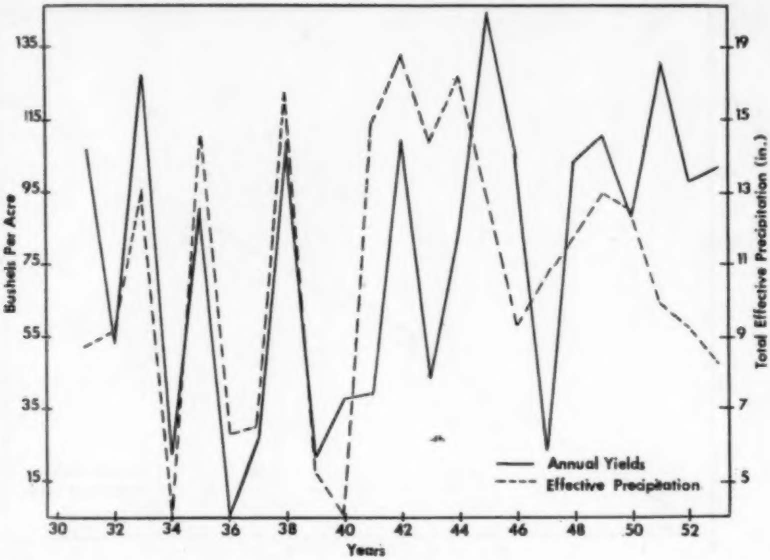


FIGURE 1.—Average annual potato yields for all rotations and total effective precipitation at the Box Butte Experiment Farm during the 1931 to 1953 period. Hail damage affected yields in 1932, 1943, 1944, 1945, 1946, 1948, and 1950.

The amount of soil moisture available at planting time depended upon the amount of effective preciptation from October 31 to June 1. Yields were correlated closely to the amount of available soil moisture in the top 5 feet of soil at planting time (Figure 2). Potato plants were able to procure moisture from a depth of at least 5 feet when the moisture had become exhausted at higher levels. When soils were filled to their field carrying capacity — approximately 6.69 inches — to a depth of 5 feet at planting time, good crops were produced even when there was little effective rainfall during the summer. Approximately 5 to 6 inches of stored moisture was necessary to produce crops large enough to pay production costs — that is, a minimum of 50 bushels per acre.

When the soil was dry below a depth of 2.5 feet at planting time, which was often the case when potatoes followed small grain, the duration of the life of the plants and the production of a crop depended upon the occurrence of effective rains during August. A detailed analysis of precipitation and other environmental effects on tuber growth has been previously published (2).

*Effect of Previous Crop upon Yield and Quality.* — The kind of crop preceding potatoes was responsible for large differences in their yield (Table 1). The lowest mean yield of potatoes for the 1941-1953 period was produced with continuous cropping. Although low yields were produced after corn, they were similar to those after small grain. Higher yields were produced after field beans and those after summer fallow were

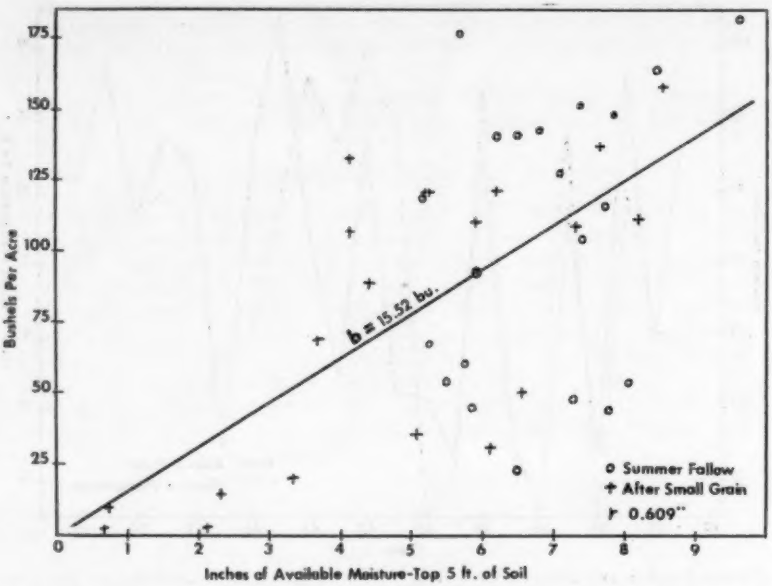


FIGURE 2.—Average potato yields after summer fallow and small grain from two 5-year rotations as correlated to inches of available moisture stored in top 5 feet of soil at planting time. Large deviations from regression occurred in a few years due to hail damage or exceedingly high seasonal rainfall.*

*Estimated Y = 15.52X — 0.19

highest of all. In contrast, during the previous decade, potato yields following corn were higher than those following small grain. This was correlated with less available preplanting soil moisture in the small grain plots. Mean available preplanting soil moisture for the years 1941 to 1953 was similar in corn and small grain.

Yields after summer fallow were good enough to warrant growing the crop in all of the 23 years except those in which hail or some other calamity of nature seriously damaged the crop. In 11 of the 13 years, from 1941 to 1953, the yields after summer fallow were greatest having been exceeded only when potatoes followed small grain in 1942 and following beans in 1952. In each of the 13 years the yields following corn were lower than those after fallow.

The previous crop had little effect upon the prevalence of scabby and other types of defective tubers, or upon the percentage of U. S. No. 1 tubers. Consequently, the yield of U. S. No. 1 potatoes followed the same trend as total yields with respect to the effect of previous crops (Table 2).

*Effect of Length of Interval between Potato Crops.* — The plan of the rotations provided for the comparison of 5 year and 3 year rotations in which potatoes occurred only once in the rotation cycle (Table 2).

TABLE 1.—*Average annual total yields of potatoes following various crops (in bushels per acre) in the 13 year period (1941-1953), and 1931-1940 averages for 3 rotations.*

| Previous Crop and Rotation No. | Years | | | | | | | | | | | | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1941-1953 13 Yr.[1] | 1931-1940[3] |
| Fallow (53,56) | 52.9 | 119.8 | 59.2 | 114.4 | 185.7 | 159.9 | 32.8 | 138.6 | 140.7 | 121.6 | 175.2 | 102.9 | 154.2 | 120.4 | 85.3 |
| Corn (31,51,54,55) | 35.1 | 107.6 | 41.3 | 76.7 | 139.1 | 83.2 | 16.5 | 96.8 | 98.6 | 79.3 | 131.4 | 101.9 | 99.7 | 85.2 | 62.1 |
| Beans (37) | 43.0 | 117.7 | 56.2 | 97.2 | 142.9 | 129.2 | 22.7 | 86.7 | 141.7 | 77.3 | 149.5 | 113.8 | 110.3 | 99.1 | .. |
| Potatoes (11A,11B) | 43.8 | 85.9 | 34.9 | 64.2 | 100.2 | 101.2 | 9.9 | 68.1 | 86.6 | 67.9 | 121.1 | 83.9 | 70.2 | 72.1 | .. |
| Small Grain (32,52) | 38.0 | 129.6 | 46.0 | 83.9 | 140.7 | 100.1 | 34.6 | 121.5 | 110.9 | 97.1 | 101.3 | 74.5 | 79.2 | 89.0 | 51.6 |
| Average[2] | 42.6 | 112.1 | 47.5 | 87.3 | 141.7 | 114.7 | 25.3 | 102.3 | 115.7 | 88.6 | 135.7 | 95.4 | 102.7 | | |

[1]L.S.D. .05 for Crop Sequence = 11.4 bu./acre
[2]L.S.D. .05 for Years = 18.4 bu./acre
[3]L.S.D. .05 for Crop Sequence (1931-40) = 6.8 bu./acre
Rotations 52, 53 and 54 only.

TABLE 2.—*Yields from single crop sequences and rotations reported as 10, 20, and 23 year averages, 1931 through 1953.*

| Rotation No. and Crop Sequences[1] | Average Yields in Bushels Per Acre | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1931-1940 | | 1941-1950 | | 1931-1950 | | 1931-1953 | |
| | Total | U.S. No. 1 over 1⅞" | Total | U.S. No. 1 over 1⅞" | Total | U.S. No. 1 over 1⅞" | Total | U.S. No. 1 over 1⅞" |
| | 5-Year Rotations | | | | | | | |
| 51 BCWCP | 65.6 | 25.3 | 71.9 | 36.9 | 68.5 | 31.1 | 72.6 | 31.2 |
| 52 BWWWP | 51.6 | 22.5 | 96.0 | 49.9 | 73.8 | 36.2 | 75.6 | 34.6 |
| 53 BWWFP | 85.3 | 33.1 | 114.5 | 60.7 | 99.9 | 46.9 | 106.2 | 48.4 |
| 54 BWWCP | 62.2 | 25.4 | 83.8 | 43.8 | 73.0 | 34.6 | 78.2 | 35.7 |
| 55 BCWCP[2] | -- | -- | 84.3 | 41.6 | -- | -- | -- | -- |
| 56 BFWFP | -- | -- | 112.0 | 66.2 | -- | -- | -- | -- |
| | 3-Year Rotations | | | | | | | |
| 31 BCP | 61.8 | 24.6 | 70.2 | 33.2 | 65.9 | 25.1 | 72.2 | 26.0 |
| 32 BWP | 48.5 | 14.3 | 84.5 | 39.7 | 66.5 | 27.0 | 68.6 | 25.9 |
| 35 BCP[3] | -- | -- | 68.9 | 33.5 | -- | -- | -- | -- |
| 37 BBeP | 62.8 | 24.6 | 91.5 | 44.5 | 77.1 | 34.6 | 83.3 | 35.6 |
| | Continuous Potatoes | | | | | | | |
| 11 P | 59.9 | 14.6 | 66.3 | 21.8 | 63.1 | 18.2 | 66.8 | 21.7 |
| | Average of All Rotations | | | | | | | |
| | 59.9 | 20.9 | 85.7 | 42.0 | 72.8 | 31.5 | 77.8 | 32.3 |

[1]P = potatoes, C = corn, B = barley, W = wheat, F = summer fallow, Be = beans
[2]Corn reduced to thin stand.
[3]Manure applied—6 tons per acre after potatoes.

TABLE 3.—*Average percentages[1] of potatoes of each grade, size or defect produced for 10, 13 and 23 year periods.*

| Year | A size - tubers over 1⅞" | | | | | Tubers under 1⅞" | |
|---|---|---|---|---|---|---|---|
| | U.S. No. 1 | Defective Tubers | | | | Size B (Over 1½ in.) | Size C (Under 1½ in.) |
| | | Off Type and Over Size | Harvest Cracks | Field Cuts | Scab | | |
| 1931-1940 Av. | 34.90 | 11.80 | 3.20 | 2.50 | 16.00 | 17.20 | 14.40 |
| 1941-1950 Av. | 47.90 | 11.40 | 2.80 | 3.30 | 12.00 | 17.10 | 5.40 |
| 1931-1950 Av. | 42.49 | 11.64 | 2.96 | 2.96 | 13.67 | 17.16 | 9.10 |
| 1941-1953 Av.[2] | 44.19 | 10.41 | 2.40 | 2.64 | 9.07 | 25.74 | 5.56 |
| 1931-1953 Av.[2] | 41.01 | 10.95 | 2.67 | 2.59 | 11.42 | 22.84 | 8.53 |

[1]Values shown were calculated as percentages that total production of each classification was of total yields produced in each of the three fields of each rotation each year and likewise 10, 13, and 23 year values were calculated from total production from all plots in years considered—i.e., they are not averages of percentage of individual plots or years.
[2]Includes values for the moderately scab resistant Progress variety from 1951 through 1953.

In one 5 year (Rotation 52) and one 3 year (Rotation 32) rotation potatoes followed wheat. In two 5 year rotations (51 and 54) and one corresponding 3 year rotation (31) potatoes followed corn. There was a trend over the 23 year period for highest potato yields to occur in the 5 year rotations, but the differences were not significant. This trend was not apparent during the 1931 to 1940 decade.

*Market Quality of Potatoes.* — An average of 44.2 per cent of all potatoes produced in 13 years — 1941 to 1953 — were of U. S. No. 1 quality and size, 24.5 per cent were defective tubers and 31.3 per cent were smaller than standard U. S. No. 1 size-A. In comparing the 1931-1940 period with that of 1941 to 1953 the average percentage of U. S. No. 1 tubers increased from 34.9 per cent to 44.2 per cent and that of size-C decreased from 14.4 per cent to 5.6 per cent, whereas percentages of the other grades and sizes did not change appreciably (Table 3).

Scabby tubers comprised the most serious grade defect with the Triumph variety ranging from a high of 42.3 per cent in 1933 to a low of 0.0 per cent in 1934 with an average of 13.7 per cent. The use of the moderately scab resistant Progress variety in 1951 and thereafter resulted in a greatly reduced percentage of scab as compared to Triumph in other field studies.

"Off type" tubers constituted a serious grade defect amounting to 10.9 per cent of the entire 23 year crop. The occurrence of harvest cracks and cuts varied according to the type of harvesting equipment and skill with which it was used.

## Summary

Rotation studies with potatoes were conducted under dryland conditions at the Box Butte Experiment Farm in western Nebraska from 1931 through 1953. One of the major objectives of these rotations was to ascertain the best dryland rotation practices with respect to the producton of potatoes. Production and factors affecting it during the dry cycle of 1931 to 1940 were compared with those of the 1941-1953 period of above normal precipitation.

The amount and depth of soil moisture stored at planting time and the amount and distribution of seasonal rainfall were by far the most important factors affecting potato yield and quality. Highest yields were obtained when the soil was filled to field carrying capacity to a depth of 5 feet at planting time followed by 2 to 3 inches of effective rainfall in August or early September. Approximately 5 to 6 inches of preplanting stored soil moisture was necessary to produce yields that warranted growing the crop. Summer fallowing preceding potatoes consistently provided all the soil moisture the soil could retain and resulted in commercially adequate yields.

Cropping sequence effects on total potato yields were associated with the amount and distribution of precipitation and stored soil moisture following the harvest of the crop and prior to planting potatoes. Lowest yields were produced with continuous cropping of potatoes. Lower yields were produced when potatoes followed corn or small grain than after field beans. Highest yields were consistently produced after summer fallowing.

Length of rotation (3 or 5 years) had little effect on yields and quality of potatoes, but during the 1941-1953 period yields from the 5 year rotations tended to be higher than from the 3 year rotations.

Yield of U. S. No. 1 potatoes followed the same trend as total yields. Scabby and "off-type" tubers were the major grade defects, whose incidence was influenced more by seasonal conditions than by rotations.

## Acknowledgment

Data from the rotation study was obtained by several Farm Supervisors over the 23 year period. Considerable work in summarizing data was done by Dr. H. W. Chapman, formerly of the University of Nebraska, and now located at Colorado State University. The Soils Division of the Department of Agronomy, University of Nebraska, was responsible for soil moisture determinations from 1941 through 1953.

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# EFFECTS OF GAMMA RADIATION ON SOME IMPORTANT POTATO TUBER DECAYS[1]

LOUIS BERAHA, G. B. RAMSEY, M. A. SMITH AND W. R. WRIGHT[2]

Since partial inactivation of plant pathogens by means of gamma radiation has offered a means of extending the storage and shelf life of commodities tested in this laboratory it seemed desirable to test this source of energy on some potato pathogens (1, 2). Investigations have shown that gamma radiation interferes with wound periderm formation and may make potatoes more subject to decay by certain organisms (7, 8 and 9).

Physiological reaction of potato tubers to low dosages of gamma radiation has been studied by many investigators (3, 4, 5, 6 and 8). Dosages of approximately 9000 rads[3] were found to inhibit sprouting in storage potatoes. Dosages of 9,000 to 18,000 rads caused increased after-cooking blackening and also increased the incidence of internal black spot in susceptible varieties. The common storage rots were not checked by these low dosages.

In the present report higher dosages were tested to determine whether growth of some important decay producing organisms could be checked without damaging the tubers. Considerable variation was noted in the amount of external and internal damage to tubers as progressively higher dosages were used. Individual tubers receiving the same dosage even showed differences in the amount of damage. Some tubers showed visible damage at 91,280 rads but many did not. Of the three pathogens tested only Phytophthora was sufficiently sensitive enough to low dosages, to indicate the possibility of controlling rot by this organism without seriously damaging the tubers.

This report gives the results obtained by irradiating potatoes inoculated with the following pathogens: *Erwinia carotovora*, *Phytophthora infestans*, and *Pythium debaryanum*. Notes are also given on secondary infection by Fusarium spp.

## MATERIALS AND METHODS

New B-size Florida potatoes (Red Pontiac variety) were purchased on the market and stored at 70° F. for several days until used. Selected potatoes were washed, rinsed, and dried prior to their inoculation.

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Investigation conducted by the Biological Sciences Branch, Agricultural Marketing Service, United States Department of Agriculture, in cooperation with the Department of Botany, University of Chicago. This paper reports research undertaken in cooperation with the Quartermaster Food and Container Institute for the Armed Forces, QM Research and Engineering Command, United States Army, and has been assigned number 964 in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

[2] Pathologist, Principal Pathologist, Senior Pathologist, and Associate Pathologist, respectively, Biological Sciences Branch, Agricultural Marketing Service, United States Department of Agriculture, University of Chicago, Chicago, Ill.

Artificial inoculations of *Erwinia carotovora* were made by puncturing the surface of each potato twice with seven evenly spaced pins held in a cork stopper, and immediately immersing the potatoes in a suspension of the bacteria in sterile distilled water. All inoculated potatoes were transferred to humidity chambers for 6 hours at 70 to 75° F., and then stored 14 hours at 38 to 41° in a refrigerator. The high and low temperatures served to reduce the progress of the infection without interfering with its establishment prior to irradiation. Four potatoes were packed in polyethylene bags and placed in a No. 2 can for each replicate. Each dosage was replicated at least four times, and the entire experiment repeated two or more times. Control samples were similarly treated but were not irradiated. Samples were kept at 38 to 41° F. prior to irradiation at the Argonne National Laboratory. Temperatures during irradiation were not determined. About 1 hour after irradiation the cans were opened and the lids replaced loosely to permit ventilation. Inspections made at this time indicated no visible rotting of the controls or of any irradiated potatoes. Notes were taken on the progression of soft rot and the extent of any alterations to the skin and flesh with respect to color and texture during the holding period at 70 to 75° F.

For inoculations made with *Phytophthora infestans*, the procedure was similar to that followed with *Erwinia carotovora*, with the exception that potatoes inoculated with the sporangia of *P. infestans* were incubated for 20 hours in sealed humidity chambers at 70 to 75° F. instead of at two different temperatures.

Inoculations with *Pythium debaryanum* were made by striking two opposite sides of a potato with a small hammer, resulting in tissue shattering bruises. Each potato was then immediately immersed in a suspension of *P. debaryanum* hyphae prepared by grinding five 10-day-old agar-slant cultures of the fungus in a blendor containing one liter of sterile distilled water. All inoculated potatoes were transferred to humidity chambers and incubated for 18 to 20 hours at room temperatures (70 to 75° F.). Procedures for post irradiation handling and the recording of data were the same as given for *E. carotovora* and *P. infestans*. For each replicate, two entire potatoes or several half potatoes were packed in a perforated polyethylene bag, placed in a No. 2 can and sealed. Control samples were left at ambient temperatures before and after irradiation. Inspections made about an hour after irradiation indicated no visible rotting of the controls or of any irradiated potatoes.

The source of gamma rays was fuel elements from the Atomic Energy Commission's Material Testing Reactor in Arco, Idaho, and arranged in the high level gamma irradiation facility at the Argonne National Laboratory, Lemont, Illinois. Cans containing the material to be irradiated were placed in water-tight aluminum urns and lowered into a rack in 17 feet of water on the floor of the tank, adjacent to the cooling upright fuel elements. Urns were rotated at a constant speed of 2 rpm. Unless doses are described as exact, they are approximate within 10 per cent.

## Results

The results of two series of experiments with *Erwinia carotovora* showed that this pathogen grew and caused typical soft rot at all dosages

tested, ranging from 17,700 to 477,400 rads. None of the potatoes survived a 10-day holding period at 70 to 75° F.

No external injury to Red Pontiac potatoes by gamma radiation was observed at a dosage of 91,280 rads. At higher dosages, injury was evident as changes in texture and color of the skin and flesh as shown in figure 1 and table 1. At very high dosages the interior tissues were discolored, as in blackheart. The tubers became soft and punky and the skin varied from brown to black.

TABLE 1.—*Extent of alteration of texture and skin color following high dosages of gamma radiation and subsequent storage of Red Pontiac potatoes for 18 days at 70 to 75° F.*

| Dosage Rads | Textural Characteristics and Skin Color Changes |
|---|---|
| 1,825,600 | Severe symptoms of radiation injury apparent 4 days following irradiation. Surface blackened, flesh very soft, vascular region and pith areas especially darkened.* |
| 912,800 | Skin dark around buds, lenticels sunken, giving pitted or rough appearance to surface; flesh generally soft and blackened beneath surface areas showing discoloration.* |
| 684,600 | Skin slightly blotched and blackened. Lenticels sunken, giving pitted and roughened appearance; vascular ring darkened prominently. Flesh blackening under darkened skin areas;* flesh soft. |
| 456,400 | Surface pitted, lenticels sunken, skin roughened; flesh discolored beneath surface blotches;* flesh soft. |
| 273,840 | No surface or internal blackening, lenticels not sunken; flesh soft; otherwise as control. |
| 182,400 | As for 273,840. |
| 91,280 | As control. |
| Control (0) | Skin color natural; no surface pitting; flesh white and firm. |

*Internal symptoms resemble "Black heart."

The experiment with potato tubers inoculated with *P. infestans* showed that no tubers were infected that received 45,640 rads (the lowest dosage tested) or above. Final inspections were made after 15 days storage at 70 to 75° F. after irradiation at dosages ranging up to 456,400 rads. The control samples were all severely infected and bore protruding tufts of mycelium within 5 days. Two experiments, testing the effects of gamma radiation on the germinating spores of *P. infestans* on Tochinai solid agar cultures, showed this fungus to be extremely susceptible to doses as low as 22,820 rads.

In one experiment all potatoes, including the control samples, were contaminated by *Fusarium* spp. Since infections by *Fusarium* were found in all irradiated and unirradiated tubers, it is evident that the highest

[3]Rad, the amount of ionizing radiation that would deliver 97.5 ergs to a gram of wet tissue.

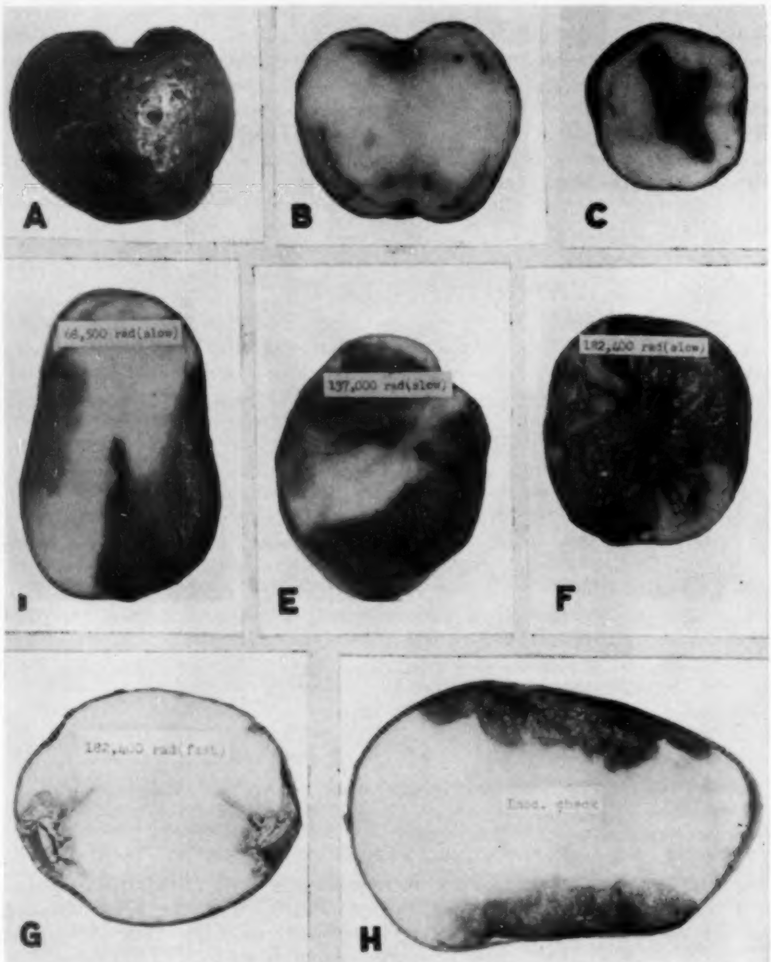


FIGURE 1.—A, B, and C — Radiation injury of uninoculated Red Pontiac potatoes. A, pitting and skin discoloration at 456,400 rads; B, vascular discoloration and blotching of flesh at 684,000 rads; C, "blackheart" at 912,800 rads, and similar injury observed at dosages as low as 456,400 rads.

D-H — Red Pontiac potatoes inoculated with *Pythium debaryanum* showing typical decay after irradiation at fast and slow rates (see text). D, 68,500 rads (slow); E, 137,000 rads (slow); F, 182,400 rads (slow); G, 182,400 rads (fast); and H, inoculated unirradiated control held 12 days at 70-75° F.

dosage (456,400 rads) tested in this experiment did not kill the spores or hyphae harbored on the surface of these potatoes. In addition, increased susceptibility of irradiated potatoes caused by the inhibition of wound periderm formation may possibly account for the appreciable amounts of *Fusarium* rot observed at the highest dosage tested.

Increased susceptibility to decay of irradiated potatoes is indicated in the experiments with Pythium (Figure 1) where tubers D, E, and F showed more decay than H, the unirradiated check.

The Red Pontiac potatoes inoculated with *P. debaryanum* showed that dosages of 68,500 to 91,300 rads were sufficient to reduce the incidence of decay for one week at 70 to 75° F. when compared with the unirradiated controls. In another experiment neither of these dosages was effective in curtailing the progress of infection during a 7-day-holding period. This seeming disparity of results indicated that differences in the dosage rate or time required to apply a given dosage was important. For dosages of 91,300 rads, the dose rates were appreciably different in the two experiments.

To test the effects of dosage rates, an experiment was conducted in which the slow rate was about one-half the fast rate. The rates of flux held nearly constant for each of the dosages tested were approximately 7,000 rads per minute for the fast rate and 3,000 rads per minute for the slow rate.

The data on the effects of various dosages of radiation and two dosage rates on potatoes artificially inoculated with *Pythium debaryanum* 18 to 20 hours prior to irradiation and subsequent storage at 70 to 75° F. for 12 days showed that dosages of 37,600 and 68,500 rads are ineffective at either a fast or slow rate in curtailing the development of decay. At each of these dosages, the rotting was at or near the same rate as in the unirradiated controls. Potatoes irradiated at levels of 137,000 and 157,600 rads yielded different rotting patterns, depending on the rates of flux. A comparatively fast rate of 7,000 rads per minute for dosages of 137,000 and 157,600 rads gave appreciably greater reductions in both rate of decay and the total number of rotted potatoes after 12 days at 70 to 75° F. The potatoes irradiated at the slow rate of 3,000 rads per minute at 137,000 rads showed a reduced rate of rotting when compared with the unirradiated controls, but were completely rotted by the 8th day after irradiation. Similarly, at 157,600 rads, when the slow rate of flux was used, there was a decrease in the rate of rotting but all samples, with one exception, were rotted by the 8th day after irradiation. The greatest difference between results obtained in comparing a fast with a slow rate of flux was found at 182,400 rads (Figure 1). At this dosage, none of the potatoes receiving a fast flux showed rot, whereas at a slow rate, no rotting was visible on the 4th day but rot was noticeable after the 6th day in 2 out of 5 samples. Finally, at 228,000 rads, no rotting was evident after a fast or slow rate of flux. Evidently, both dosage and rate of flux, to yield a certain dose, are important in assessing effects of radiation on the reduction of decay by *P. debaryanum*. This suggests that there may be a safe dosage rate for different commodities which will minimize textural and color changes as well as reduce decay at comparatively low dosages.

## Summary

Doses of gamma radiation ranging from 17,700 to 477,400 rads failed to prevent decay in potatoes inoculated with *E. carotovora*. The tubers irradiated at the higher dosages showed extensive external and internal discoloration as well as softening.

A dosage of 45,640 rads was sufficient to prevent decay without damage to the tubers inoculated with *P. infestans*. In plate cultures, the lowest dose tested (22,820 rads) prevented further growth of 24 hour cultures of this organism.

Development of *Fusarium* rot at dosages as high as 456,400 rads indicated that gamma radiation did not control this fungus naturally harbored on the surface of tubers.

Potatoes inoculated with the leak organism (*P. debaryanum*) reacted differently to a given dose of radiation depending on whether the dose rate was fast (7,000 rads per min.) or slow (3,000 rads per min.). Dosages up to 68,500 rads at either of these rates were ineffective in curtailing the development of decay. At dosages of 137,000 and 157,000 rads a fast rate gave almost complete control of decay, whereas the slow rate was ineffective. At 182,400 rads the fast rate gave complete control and the slow rate partial control. At 228,000 rads both the fast and the slow rate gave complete control of decay, but damaged the potatoes. Since a slight softening of tubers occurred at 137,000 rads, it is evident that control of this decay by gamma radiation would not be practical.


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## NEWS AND REVIEWS

Members attending 43rd Annual Meeting at the University of New Brunswick, Fredericton, N. B., Canada.

# HIGHLIGHTS OF THE 43rd ANNUAL MEETING OF THE POTATO ASSOCIATION OF AMERICA AT FREDERICTON, N. B., CANADA — AUGUST 12 - 17, 1959

The members who attended the 43rd Annual Meeting at Fredericton, New Brunswick were indeed fortunate because by all standards it was one of the most memorable in the history of the Association. Although made in typical rain and fog, the tour north on August 12 through the potato seed country around Woodstock, New Denmark, and Grand Falls was nevertheless a delightful affair. Arriving about noon at East Florenceville we were the guests of the McCain family on a tour of their modern freezing plant where as Robert McCain put it "they were literally up to their ears in peas." However, potato processing machinery for French fries and other products was inspected. Although not yet in operation, it was in readiness for the potato harvest. A delicious lunch was served by the ladies of Florenceville under the supervision of our gracious host Mrs. A. D. McCain.

At New Denmark we visited the potato plot lay-out on a typical Provincial Illustration Farm owned by Mr. Jens Larson and from there motored down the famous ski-run road to Grand Falls. Here we visited the huge starch plant of the Valley Cooperative, Ltd. and were amazed

by the size and extent of the imported machinery used for the production of raw and modified potato starch. Leaving the main road at this point we precariously made our way toward Little River and the "Riviera" as guests of Mr. Leon Rideout, manager of the Valley Cooperative, Ltd.

For many of us this was one of the highlights of the tour. Welcomed by a Canadian brass band playing Dixie music we sat down in a specially built "Riviera" to a repast of chicken stew par-excellence, flavored with the inimitable bubbling hospitality of our French-Canadian hosts. The only 'fly in the ointment' was the necessity to leave before the local "hoe-down" commenced. Tired and weary but happy with memories of a wonderful day we arrived at Fredericton after midnight.

## Excellent Program

Anyone could glance over the titles of the papers given during the meetings for the next three days and feel assured of the excllence of the scientific program. Through the efforts of Dr. R. H. Larson, who arranged for six foreign speakers, the program also took on a distinctive international flavor — even beyond the fact that the meetings were held at the University of New Brunswick. Seldom, if ever, have we had such an array of invitation papers by foreign authorities, most of whom had travelled many thousands of miles to attend.

The facilities at the University met our every wish. Aitken House, new a year ago, was bristling with native hardwoods and equipped with all the latest comforts of dormitory life. Conference rooms were abundant and excellently furnished and the food at the cafeteria was ideal. Equipped with every modern facility the lecture hall was ideal for both speakers and audience.

The inspection of the Department of Agriculture Research Station at Fredericton, topped off with a delicious chicken barbecue, was a delight both for the members who visited the extensive plot lay-outs and for the ladies who visited the beautiful flower gardens.

The Annual Recognition Banquet held at the Lord Beaverbrook Hotel climaxed the meetings. Led by a Scottish bagpiper dressed in full regalia and playing one or perhaps two tunes (there seemed to be some doubt about this) the guests and speakers circled the beautifully flower-decorated dining hall to their places of honor at the long speakers' table. A delicious dinner of salmon from the St. John River was served topped off with a unique dessert known as "bake apple" (Rubus chamaemorus) which was flown from the Arctic for the occasion.

In order to keep matters even, Mother Nature provided another rainy day for the trip to St. John, Alma, and Fundy Park. But the whole countryside was lush green and with the ever-present St. John River providing scenic beauty at every bend and turn nothing could be more beautiful. To a potato-minded group the trip was especially enjoyable because no blight had yet appeared. The inspection of the plots at Alma, the bountious lobster feast, and the atmosphere of gracious hospitality created memories that will long be remembered.

None of this, of course, happened by accident. It was patently the result of much planning and cooperative effort on the part of all our Canadian friends who thought of every detail for our comfort and enjoy-

ment. To all these kind people we give a rousing cheer for a "good effort" well done. Someday perhaps our children or mayhap or grandchildren will come to New Brunswick to see the beauties we have tried to describe and to feel the hospitality of the people — and to learn perhaps how to spell Mermerimammericook and some of the even harder intriguing Indian names.

Many of those in attendance left on August 17 for Montreal to attend the Botanical Meetings but a large number motored to Presque Isle, Maine to inspect Aroostook Farm. As guests of the Maine Potato Growers' Association we were served a delicious luncheon at the Northeastland Hotel and thus wrapped up a series of meetings and delightful experiences that will live in our hearts for years to come. Your old friend,

G. V. C. HOUGHLAND

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## BOOK REVIEW —

### THE TECHNOLOGY OF FOOD PRESERVATION

THE TECHNOLOGY OF FOOD PRESERVATION, a new book by Dr. Norman W. Desrosier, Professor of Food Technology at Purdue University is the first book devoted primarily to the fundamental principles of food preservation.

It includes chapters on the principles of refrigeration, freezing, canning, drying and dehydration, fermentation and pickling, jelly, jam and preserve making, grading, chemical additives and radiation.

This book will be of great value to processors who use the information to improve their products and processes.

Food spoilage and the effect of food preservation and storage on nutrients and food value are fully discussed.

The chapter on Preservation of Food with Ionizing Radiations is particularly complete and contains the first technically accurate but simple presentation of the fundamentals of food preservation by radiation. The author is particularly qualified to discuss this subject because of his years of research in this field.

The food technologist and food processor will find this book of particular value, however, it will also be of considerable value to the home economist.

Published by the AVI Publishing Company, Inc., P. O. Box 388, Westport, Connecticut, this book contains 425 pages, 181 illustrations and 46 tables as well as a complete index and a valuable appendix.

Price. Domestic, $8.50; Foreign, $9.50.

# USDA SCIENTISTS FIND HOW LIGHT CONTROLS PLANT DEVELOPMENT

The triggering mechanism for all plant development has just been found by U. S. Department of Agriculture scientists. The discovery promises to be the key to man's complete control of plant growth from seed germination through plant flowering and fruiting.

The scientists have recovered the pigment forms from corn plants and have removed some of the impurities. The material isolated is a protein, and functions as an enzyme. The pigment forms can be converted from one to the other outside of the plant, and this action can be detected by laboratory instruments. In the past conversion of one form to the other was detected only by plant response. Now the presence of each can be detected by absorption of red or far-red light.

As the pigment forms are purified further, the scientists believe that they will be able to identify and modify them at will, and thereby influence the character of plant growth.

For scientists the discovery opens the door to further research of this triggering action to enable man to tailor-make plants for his needs. Possible results are crops of special heights for better harvesting, flowering of plants at times convenient to man, or for better control of plant pests.

Dr. Byron T. Shaw, Administrator of USDA's Agricultural Research Service, hails the discovery as an outstanding basic research achievement. "It is the kind of discovery envisioned when the Department's new pioneering research laboratories were established. It provides means for the better control of plant development for specific purposes — for better food, fiber, and industrial raw material," he said.

Drs. Harry A. Borthwick and Sterling B. Hendricks at the Agricultural Research Center, Beltsville, Md., made the discovery in studying the effects of differences in the color and intensity of light on growth responses such as flowering, seed germination, elongation, and color production. Associated in the research also were Harold W. Siegleman of the Agricultural Research Service and Carl Norris and Warren Butler, both of the Agricultural Marketing Service.

It has long been known that light controls the reddening of apples by governing the formation of the coloring material. The side of the apple facing out from the tree is usually redder than the side facing the center of the tree.

Recently the scientists found the critical range of light for apple coloring to be in the red region of 6,200 to 6,900 Angstrom units. Above this region the amount of reddening of the apple declines rapidly as the wavelength of light increases toward far-red.

With soybeans growing on short days and long nights, an extremely short exposure to red light during the night will prevent the plant from flowering. Conversely, an equally short period of far-red light causes the plant to flower. However, if the intensity of far-red light is increased 100 times, the plant again fails to flower.

Drs. Borthwick and Hendricks have found growth responses to be governed by a reversible chemical reaction that is controlled by the color

and intensity of light acting upon two pigment forms present in invisible quantities.

One form of the pigment absorbs red light and the other far-red light. The pigment form that predominates in a plant depends upon the color of light to which the plant is exposed. The form produced by the action of red light regulates plant growth and can absorb far-red light. However, if this form absorbs far-red light it is converted back to the red-absorbing form that does not regulate plant growth.

To obtain the various colors of light for the experiment, the scientists directed white light from a high-intensity electric arc through a prism to break it into all the colors of the spectrum as in a rainbow. The portion of light used in this work was the red part of the spectrum from yellow (5,800 A.) to far-red (near the limit of visible red light (7,000 to 7,500 A.), which is near the range of infra-red or heat energy.) An Angstrom unit, a measure of wavelength of light, is one millionth of a centimeter.

Colors in the yellow and orange range of 5,800 to 6,300 A. are absorbed largely by the red-absorbing pigment form, moving the photoreaction toward the production of the growth regulating form.

The red-absorbing form can utilize more light in the 6,300 to 6,700 A. region, red-orange to red than in other ranges. Therefore, this is the range requiring the least amount of light energy to convert this pigment form to the regulating pigment. Both pigment forms are present in this range of colors, but the regulating type predominates.

Both forms of pigment are present in about equal amounts in the 6,700 to 7,200 A. (red) region, with the midway point in the reaction about 6,950 A. At longer wavelengths the reaction moves toward the red-absorbing form and the shorter wavelengths (toward yellow) stimulate the production of the growth regulating form.

In the far-red region of 7,200 to 7,800 A. light absorption by the regulating form of pigment is at maximum, moving the reaction toward the reformation of the red-absorbing form.

It is the selective absorption of the various colors of light by the two pigment forms that apparently governs many phases of a plant's development, including flowering, germination, and elongation, and that promises to add even more knowledge of plant development.

Maximum suppression of germination of Great Lakes lettuce seed takes place near 7,000 A. The scientists also found that elongation of the lettuce root was controlled by the color of light. Elongation was found to be suppressed at 6,100 A. (orange) and stimulated by exposure to light in the far-red region of 7,500 A.

The intensity of light also has a marked effect on the germination of lettuce seed. Exposed to light of 7,500 A., for example, an intensity of .8 microwatts per square centimeter results in about 70 per cent germination. An increase to two microwatts gives about 35 per cent germination, while 30 microwatts reduces the germination to almost zero.

These differences, the scientisis point out, vary according to the wavelengths of light being used in the experiment. Below wavelengths of 6,800 A. there are no appreciable differences in germination between the three levels of light intensity (.8 to 30 microwatts).

## POTATO JOURNAL BINDERS AVAILABLE

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It's a strong, sturdily constructed binder — handsomely bound in brown simulated leather with "American Potato Journal" embossed in silver on the front cover and backbone. A label holder for identifying the volume number is also attached. Each binder will hold 12 issues (one volume) of your Potato Journal. If you prefer to have a binder that will hold 2 volumes, these can also be furnished at slight extra cost.

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You no longer need to search for your copies of the Potato Journal in your desk or book case. You can keep them handy in a fine inexpensive binder. The binders cost only $2.50 each and we will pay the postage if you send payment with your order. Or, if you prefer, we will bill you $2.50 plus 50 cents for postage and handling.

To secure binders for all of your American Potato Journals, fill in the coupon below, enclose check or money order, and mail to John Campbell, Treasurer, The Potato Association of America, Nichol Avenue, New Brunswick, New Jersey.

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JOHN C. CAMPBELL, *Treasurer*
THE POTATO ASSOCIATION OF AMERICA
NICHOL AVENUE
NEW BRUNSWICK, NEW JERSEY

Dear Mr. Campbell:

Please send me .................... American Potato Journal binders.
Number

☐ I enclose $...................., at $2.50 each, you pay postage.

☐ Bill be for $...................., @ $3.00 each, which includes postage and handling charges.

☐ I am interested in the larger binder to bind two volumes of the American Potato Journal.

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PICTURES OF ANNUAL MEETING

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G. V. C. Houghland
4338 Clagett Road
Hyattsville, Maryland.